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SEAKEEPING ANALYSIS OF A HIGH-SPEED SEARCH AND RESCUE CRAFT BY LINEAR POTENTIAL THEORY

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ABSTRACT

The seakeeping performance of a Search and Rescue (SAR) craft in regular waves is investigated. A numerical hydrodynamic analysis was carried out on the Severn Class lifeboat of the Royal National Lifeboat Institution (RNLI) by using linear potential theory. The Severn is a 17-metre all-weather SAR craft capable of a maximum speed of 25 knots. A global finite element model of the lifeboat that integrates hydrodynamic and structural analysis was developed with the engineering package MAESTRO. Bottom pressure envelopes, motion responses and induced wave loads were predicted using both strip theory and panel methods. The equations of motion are formulated using the structural mesh rather than a hydrodynamic mesh. This results in a balanced structural model for investigation of the global structural response, without need for applying inertia relief. The predicted wave-induced motions in head and bow quartering seas are in agreement with the results of experimental tests by Fridsma [1]. With increasing speed, the motions also increase to a great extent and the motion peaks appear to shift to longer wavelengths. The maximum heave and pitch responses are found to occur at wavelengths between 1.5 and 3 times the craft length. The results from this research will contribute to the development of a numerical model for the prediction of the loads that the craft is likely to experience throughout its operational life and its consequent structural response. The numerical model will be validated through extensive comparison with experimental model tests and full-scale trials.

NOMENCLATURE

β	Wave direction
λ	Wavelength
LCG	Longitudinal Centre of Gravity
LOA	Overall Ship Length
LR	Lloyd's Register
RAO	Response Amplitude Operator
RNLI	Royal National Lifeboat Institution
SAR	Search And Rescue
VBM	Vertical Bending Moment
VCG	Vertical Centre of Gravity

employed by the Royal National Lifeboat Institution (RNLI) with the design life of the latest Shannon Class lifeboat being 50 years.

The RNLI's Severn Class first entered service in 1995 and it would now be approaching the end of its operational life. However, due to its exceptional in-service performance, the RNLI has been investing in a life extension program to lengthen its service life to 50 years [2]. Given the chance to bring a mid-life upgrade to the Severn, work was also undertaken to explore how new technologies and approaches could further improve its in-service performance. Many of the Severn Class lifeboat fleet are already being fitted with new, more modern engines to enhance their capabilities.

It is well known that restrictions to the operational envelope of a craft are due to a variety of balancing requirements. Optimum weight, structural strength, available propulsive power, equipment functionality, crew endurance and safety are all factors that determine the maximum allowable speed for a given sea state. These factors and how they interact are represented conceptually by Figure 1. In this

1. INTRODUCTION

The design and development of a new lifeboat class is a long and intense process, which involves model testing, sea trials and periods of evaluation before the new lifeboat enters service. Due to a number of reasons, including considerations of the service life of a lifeboat, the need to respond to changing patterns of casualties and the possibility to embed new materials and technologies that become available, lifeboat classes are only replaced after extended years of service. This period of time has typically been of 25 years for the lifeboats designed and

context, an area of potential improvement was found in the structural response and design limit with respect to the other limitations. Typically, RNLI all-weather lifeboats have a maximum speed of 25 knots in a Beaufort Force 2 and 17 knots in a Force 7, although this can be a subjective measure. Furthermore, with improved seat protection [3], the perception of the coxswain in charge of the lifeboat could limit their ability to appreciate the slamming loads being sustained by the structure. When the ride quality limit is increased, this has the potential to push the structural design close or even beyond the structural design limit [4].

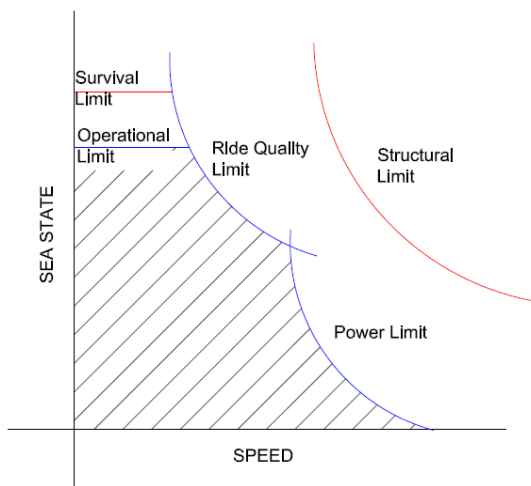


Figure 1. Graphical representation of requirements.
[Reproduced from [5]]

This paper reports on a major project that is being undertaken by the RNLI and Newcastle University, with support from Lloyd's Register. The main aim is to develop a set of guidelines embedding all these limiting criteria. These guidelines will be initially tailored to the needs of the RNLI's design team as well as those of lifeboat operators, but will have the potential to be adapted for the requirements of the wider marine industry.

To achieve this, a numerical model was considered the appropriate tool to carry out a detailed investigation into the structural response of the craft to the loads experienced in the various operating conditions. Due to the complexity of the problem, validating the model with results from extensive experimental model tests and full-scale trials was also considered necessary.

This paper focuses on the development of the numerical model for the prediction of motion responses, hull girder loads and bottom pressure envelopes of the Severn Class lifeboat in regular waves.

2. BACKGROUND

2.1 LOAD PREDICTION METHODS FOR HIGH-SPEED CRAFT

One of the basic requirements for optimising the structure is its strength assessment against the loads that the craft experiences in its operational life. This can only be achieved if there is a certain degree of confidence in the prediction of those loads. Depending on the predominant forces involved and on the vessel's operating conditions, different approaches are adopted. The load prediction problem can usually be treated as nearly static for conventional displacement ships travelling in a moderate seaway. For high-speed craft the structural-loading situation becomes more complicated [6].

A craft travelling at speed and in rough seas is subject to significant loads that are time dependent and different in nature, which is the main reason why the RNLI specifies a speed restriction as described above. Both hydrostatic and self-weight loads can be determined for a given ship condition with a high degree of accuracy. However, the same cannot be said for the wave-induced hydrodynamic loads. The prediction of these loads is less reliable. There is also limited guidance on how to treat transient effects such as slamming, which change rapidly in time and space [7].

A number of methods are available for predicting the loads imparted to a craft that travels at high speed in a seaway. Semi empirical methods [8,9] appear to be the state-of-the-art for practical design. The fundamental assumption underlying these methods is that a transient non-uniform pressure distribution can be modelled as static and uniform. Pressures for the structural design are modelled as "equivalent static pressures" that, if applied to the structural component, will

produce the same maximum deflection and peak stress as those produced by the actual loading [8]. Semi-empirical methods have been implemented in the scantling rules of most Classification Societies such as ABS [10], DNV [11] and LR [12]. The approach usually adopted in these rules is that the spatial distribution of the bottom impact pressure along the waterline length of the hull is determined by a longitudinal distribution factor. In the case of the *Rules and Regulations for the Classification of Special Service Craft (SSC)* from Lloyd's Register [12], the values assumed by the longitudinal distribution factor depend on the operation mode of the craft and whether the craft remains in continuous contact with the water surface. If this is not the case (i.e. a vessel operating at very high speeds or in extreme seaways that cause the craft to leave the water surface) a uniform pressure is applied along the entire waterline length of the hull.

Theoretical approaches to tackle the planing and hull-water impact phenomena have been developed since the 1920's and 1930's with the pioneering works of Von Karman [13] and Wagner [14] in the context of seaplanes. Through the years, many methods have been developed for the calculation of the slamming pressure on a body that impacts on the water surface with a prescribed velocity. Wagner's theory has been extensively re-presented with modifications by other authors [15–17]. Advanced CFD methods based on solving RANS (Reynolds Averaged Navier-Stokes) and Euler equation have been applied to a range of 2D as well as 3D problems. Recent modelling techniques that take into account the complete fluid-structure interaction problem have been presented, for example, by Le Sourn et al. [18]. Here, the water-entry of the bow of a fast mono-hull was studied in 3D. Fluids were modelled as multi-material eulerian and solids as rigid lagrangian. The fluid-structure interaction was taken into account through a coupling algorithm.

However, the significant computational resources required by these methods do not make them a suitable option for practical design calculations [19]. The majority of seakeeping predictions are carried out in the framework of the potential theory. Potential flow solvers, which are much

faster than Euler and RANS equation solvers are indeed the most commonly used CFD tools in naval architecture [19].

2.2 THE RNLI LOAD CURVE

None of the methods described above suited the particular needs of the RNLI. This is mainly due to the extreme conditions in which lifeboats are required to operate and the advanced materials and the production technologies employed in the construction [20]. Consequently an in-house design load prediction method based on earlier studies coupled with theoretical formulations, trials and in-service experience has been used by the RNLI design team for some time [3,20]. This approach treats the design loads in terms on equivalent static ultimate pressures. The maximum ultimate pressure for the design of a new lifeboat is determined as a function of displacement and operational speed. Then, this pressure value is modified according to the longitudinal position on the hull surface and applied over the whole of the respective panel.

This method has proved to be suitable for predicting panel pressures for use in the design process [20]. However, it was considered that a more effective tool could be developed for the purpose of understanding the structural response of the craft in a variety of conditions and optimising the structure and the operational procedures.

3. DEVELOPMENT OF A NUMERICAL SIMULATION MODEL

Structural assessments require an understanding of the motions and wave-induced load effects, such as vertical bending moment or shear force in the hull girder, that the craft is likely to experience during its operational life. Generally, the global load effects for a small high-speed craft are not significantly affected by elastic deformations, since rigid body motions are dominant [21]. Hence, they can be determined through motion analysis.

As discussed in the previous section, the most common numerical tools for predicting

seakeeping motions and loads are based on potential theory and they are mainly of two categories: strip theory methods and panel methods. The former are computationally efficient and give good prediction of motions and hull girder loads. The latter are generally more suited for applying the pressure distribution to a 3D finite element model for structural assessment [22]. However, one of the challenges of both methods is transferring the pressure mapping from the hydrodynamic model to the corresponding structural model. Due to the discrepancies in the mesh used for hydrodynamic and structural analysis, this process often results in an unbalanced structural model. The “inertia relief” approach is often used to rebalance the model, however, this method may cause changes in the load distribution which affect the accuracy of the structural analysis [22].

A numerical model of the Severn Class lifeboat that integrates hydrodynamic and structural analysis was developed to overcome the mesh discrepancy issue. The design software MAESTRO (v11.2.0) was used to build a full-ship structural finite element model of the Severn. The potential flow solver MAESTRO-Wave was used to predict motions and wave loads using both strip theory and panel method. MAESTRO-Wave formulates the equations of motions based on the structural mesh rather than the hydrodynamic mesh. This results in a balanced structural model with no need for applying the inertia relief [22,23].

3.1 DESCRIPTION OF THE FINITE ELEMENT MODEL

The Severn Class is a 17-metre all-weather lifeboat, with a displacement of 42 tons, and it is capable of a maximum speed of 25 knots. Its principal particulars are outlined in Table 1. The construction materials are advanced fibre-reinforced composites. The hull bottom is a single skin shell laminate stiffened with longitudinal and transverse structure. The hull topsides, sides, deck, superstructure and bulkheads are of sandwich construction.

The generated finite element model is a full-ship model, inclusive of centreline keel, bilge keels

and superstructure, as shown in Figure 2. Shell, beam and bar elements were used to represent all the main structural components. The material properties were recovered from data supplied by the material manufacturer. The laminates properties were first calculated on the basis of the Classical Laminate Plate Theory and then applied to the finite elements as uniform orthotropic properties.

Table 1. Severn Class main particulars.

Length overall	Loa	17.00	m
Length waterline	Lwl	15.50	m
Beam max	Boa	5.62	m
Depth	D	2.52	m
Draught	T	1.37	m
Displacement (light load)	Δ	36.5	t
Displacement (full load)	Δ	42.0	t
Speed max	V	25	kn
Fuel		5600	lt
Range		250	nM

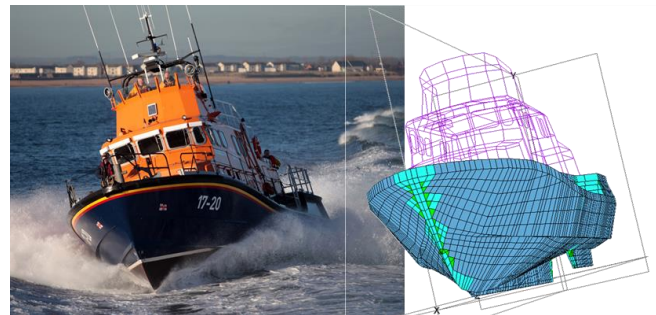


Figure 2. Severn Class Lifeboat (left) and relative FE structural model under development (right).

3.2 LOAD DISTRIBUTION AND HYDROSTATIC BALANCE

The load case considered for the initial analysis is the full load departure condition (i.e. includes full fuel, crew and operational equipment). The target displacement was chosen based on statistical analysis of the inclining test data of the Severn fleet. The masses defining the load case were input, depending on their nature, as: volume masses, scaled-up structural mass, point masses and large solid masses whose centre of gravity lies at distance from the supporting nodes (e.g.

engine and gearbox). The computed centre of gravity position matches closely the target value calculated from analysis of the inclining test data of the fleet. For reference, the discrepancies are less than 1cm in the LCG position and 17cm for the VCG.

The model was first balanced on the still waterline. Weight and buoyancy distributions are shown in Figure 3. The integrity of the model was checked by performing the hydrostatic balance also in regular sinusoidal waves of unit amplitude. Wave direction, length and phase were varied progressively in order to assess the hull girder loads in a range of headings, wavelengths and in both sagging and hogging conditions.

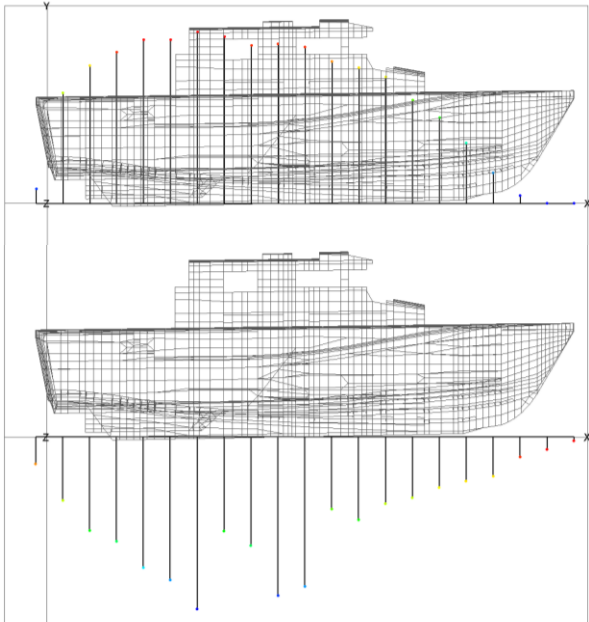


Figure 3. Buoyancy distribution (top) and gross weight distribution (bottom) in full load departure condition.

3.3 HYDRODYNAMIC PERFORMANCE IN REGULAR WAVES

Once the model was balanced, a seakeeping analysis was performed to compute the rigid body motions and the global wave loads for:

- 5 headings from head seas ($\beta=180^\circ$) to following seas ($\beta=0^\circ$) at 45° increments.
- 21 wavelengths in the range of 0.4 to 4.4 wavelength/ship length at increments of 0.2.
- 6 ship speeds from 0 to 25 knots at 5 knots increments.

The simulations were run in the frequency domain with three different linear potential theory codes embedded into MAESTRO-Wave:

- 2D strip theory using a zero-speed Green function.
- 2.5 strip theory using a Rankine Source method. This code includes a forward speed correction term in the free surface computation and it is recommended when running cases at Froude numbers above 0.4 (10 knots for the Severn Class).
- 3D panel method using a zero-speed Green function.

4 RESULTS

The output from the analysis includes panel pressure distributions, motions and hull girder loads. A characteristic carpet plot of bottom pressure distribution is shown in Figure 4. The motion displacements and hull girder loads are presented in terms of response amplitude operators (RAOs). Results are plotted per waves of unit amplitude and as function of the non-dimensional wavelength/ship length ratio. It should be noted that the simulations are based on linear theory and that no roll damping correction is applied at this stage.

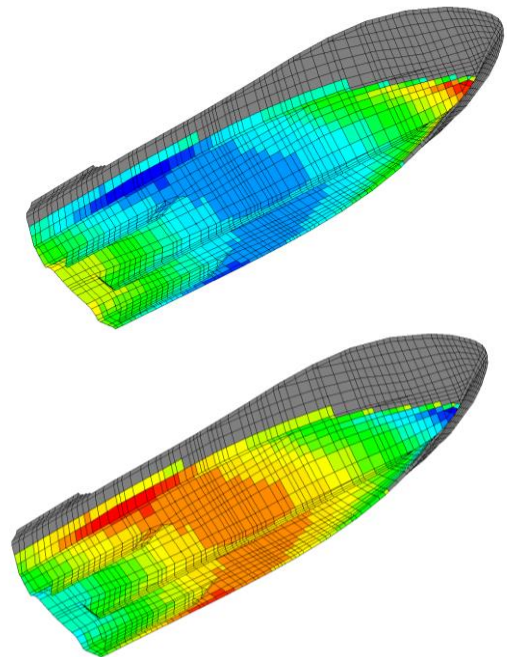


Figure 4. Wave pressure distribution at 20 knots (blue minimum, red maximum), in head waves, for sagging (top) and hogging (bottom). $\lambda/LOA=2$.

4.1 HEAVE AND PITCH MOTIONS

Figures 5-16 show the heave and pitch responses in head and bow quartering seas computed with the 2D strip theory, the 2.5D strip theory and the 3D panel method.

The same trend of heave and pitch motions are observed amongst the codes. The motions increase to a great extent with speed. As soon as the speed increases, the motion peaks shift to longer wavelengths. The maximum heave and pitch responses are found to occur at wavelengths of 1.5 to 3 times the craft length. At shorter wavelengths, increasing the speed results in smaller motions. The effect of speed becomes progressively less evident during operation in very short and very long waves.

Although the motion magnitudes predicted by the three codes are different, a common pattern could be identified. The 2D strip theory code gives generally the lowest motions, followed by the 2.5D strip theory code. The 3D panel method gives the highest motions. The discrepancy amongst the codes increases with speed to a great extent. Whilst it is unnoticeable at 0 and 5 knots, it becomes significant above 15 knots.

The results were also evaluated with reference to the experimental data presented by Fridsma [1], who carried out a series of systematic model tests of motions and accelerations of high-speed planing vessels in head waves. The motion trends are in good agreement with those by Fridsma, with only one difference: Fridsma found the maximum heave and pitch responses to occur at slightly longer wavelengths. These being from 2 to 4 times the craft length. However, it should be considered that Fridsma's tests were carried out at speed-length ratios up to 6, which would correspond to 43 knots for the Severn. It seems therefore reasonable that a larger shift of the motion peaks was observed.

As expected, the motion responses in stern quartering and following waves are much lower than those in bow and head seas. Generally, increasing the speed decreases the motions, however, the behaviour of the craft in headings with wave direction abaft the beam is more

challenging to analyse. Increasing the speed for a given wave frequency and heading reduces the encounter frequency to a point where the vessel remains stationary relative to the waves. Above that speed, the vessel overtakes the waves and the motion responses may be considerably different. It is believed that experimental tests will give more insight on the actual motions experienced in these headings, and helm inputs can be assessed and taken into account.

4.2 HULL GIRDER LOADS

Wave induced loads, such as bending moment and shear force, are to be assessed in order to construct the load cases for structural analysis. Figures 17-19 show the maximum vertical bending moment (VBM) experienced by the vessel in the whole range of headings and speeds considered, as computed by the three codes. The maximum VBM always occurs within the midship region.

There is a lower level of agreement in the behaviour of the maximum VBM amongst the codes. However, as per the motion responses, the peak values in bow quartering and head seas increase with speed as well as shifting to longer wavelengths. As shown by Figures 17-19, maximum values are significantly lower in stern quartering and following seas. This suggests that the VBM in stern quartering and following seas will not represent an extreme response of the craft to be investigated through a structural analysis. The experimental tests will be used confirm these results.

4.3 LINEARITY

As shown by Figures 5-16, the magnitudes of the motions at high speed are extremely large and may overestimate the actual response. However, Fridsma's experimental work showed that increasing the speed significantly magnifies the motions "in a manner analogous to the removal of damping from the system" [1]. He commented that sharply tuned resonant peaks in the motion responses occur at high speed-to-length ratios.

Other possible reasons for the high motion responses are:

- The likely overestimation of the maximum motions by seakeeping software. This is generally due to the poor damping of potential theory based solvers.
- A lack of linearity at high speed. The motion response appears to be linear at speeds up to 15 knots. At 20 and 25 knots the motions are magnified to a great degree. This suggests that there is a threshold speed above which

the assumption of linearity becomes questionable.

- The limit of linear theory, which is not capable of capturing the planing hydrodynamics. Indeed, linear theory takes into account the loads acting on the underwater part of the hull, as defined by the still waterline. The effects above the still waterline are neglected.

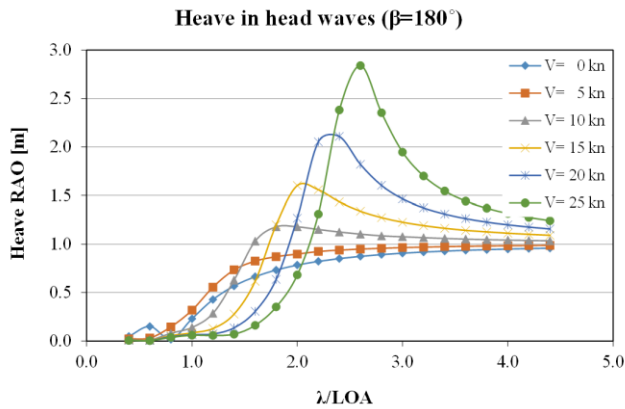


Figure 5. 2D strip theory. Heave RAOs in 1m amplitude head waves ($\beta=180^\circ$).

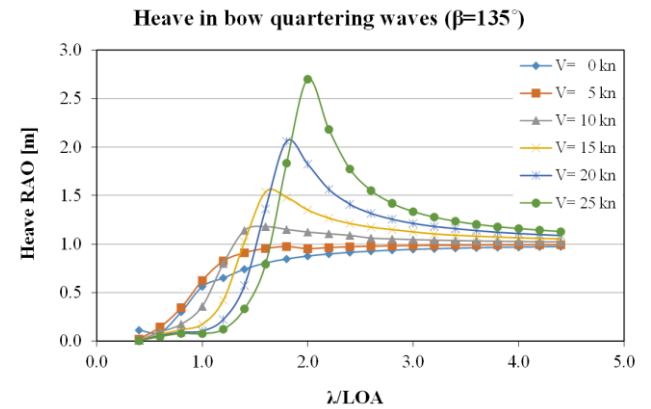


Figure 6. 2D strip theory. Heave RAOs in 1m amplitude bow quartering waves ($\beta=135^\circ$).

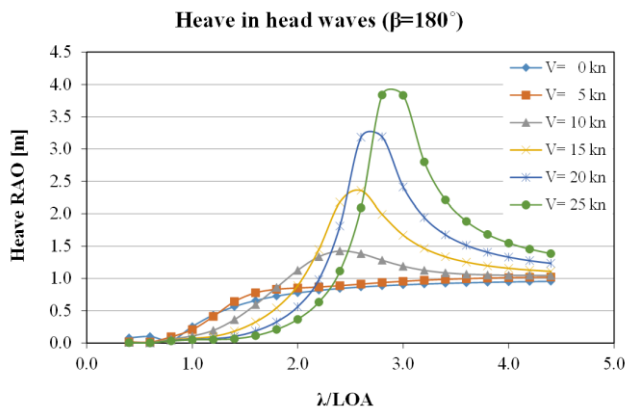


Figure 7. 2.5D strip theory. Heave RAOs in 1m amplitude head waves ($\beta=180^\circ$).

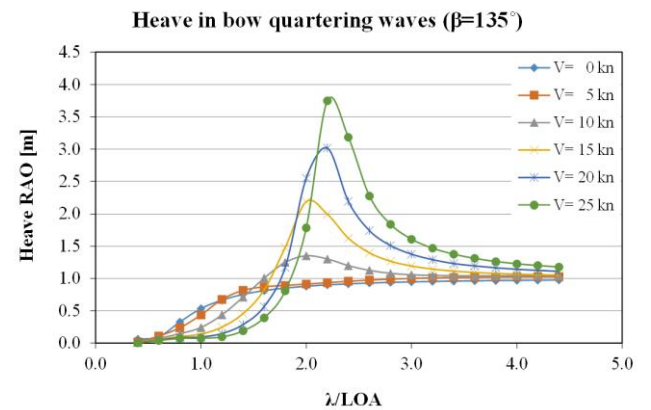


Figure 8. 2.5D strip theory. Heave RAOs in 1m amplitude bow quartering waves ($\beta=135^\circ$).

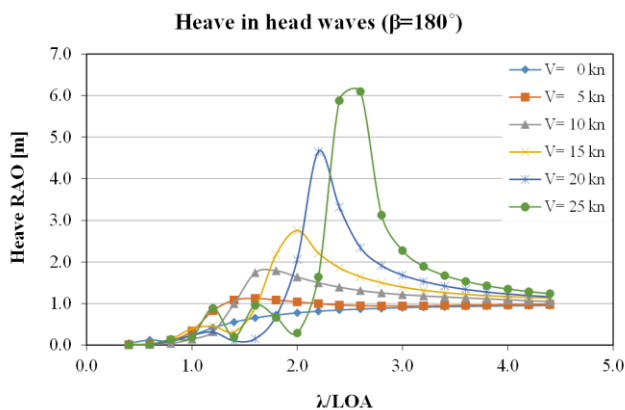


Figure 9. 3D panel method. Heave RAOs in 1m amplitude head waves ($\beta=180^\circ$).

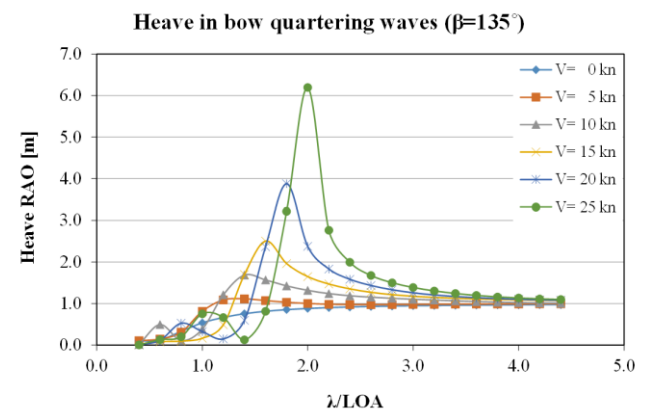


Figure 10. 3D panel method. Heave RAOs in 1m amplitude bow quartering waves ($\beta=135^\circ$).

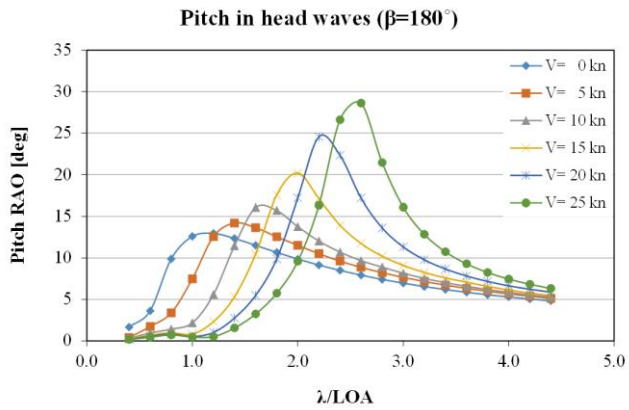


Figure 11. 2D strip theory. Pitch RAOs in 1m amplitude head waves ($\beta=180^\circ$).

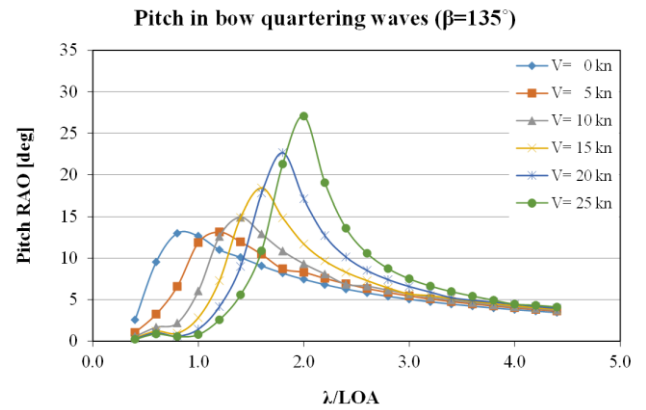


Figure 12. 2D strip theory. Pitch RAOs in 1m amplitude bow quartering waves ($\beta=135^\circ$).

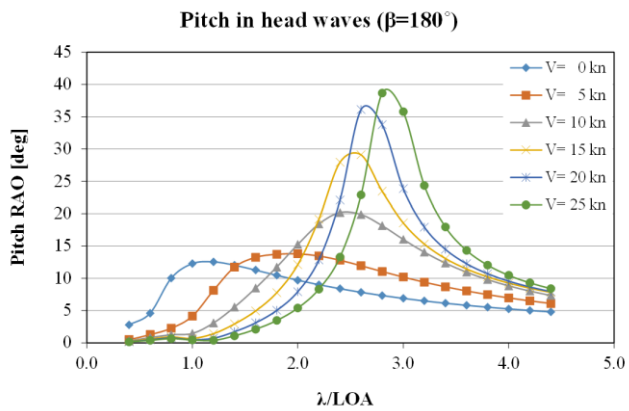


Figure 13. 2.5D strip theory. Pitch RAOs in 1m amplitude head waves ($\beta=180^\circ$).

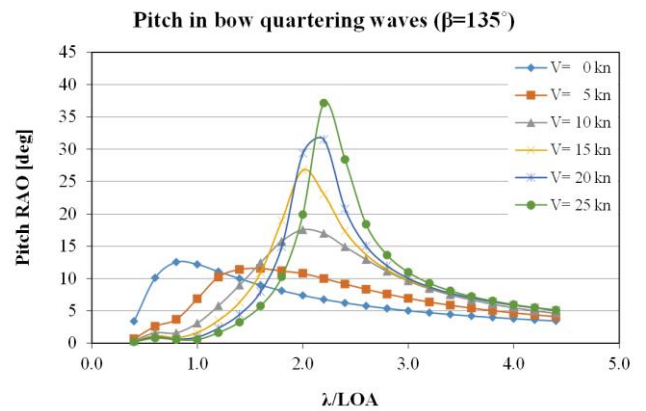


Figure 14. 2.5D strip theory. Pitch RAOs in 1m amplitude bow quartering waves ($\beta=135^\circ$).

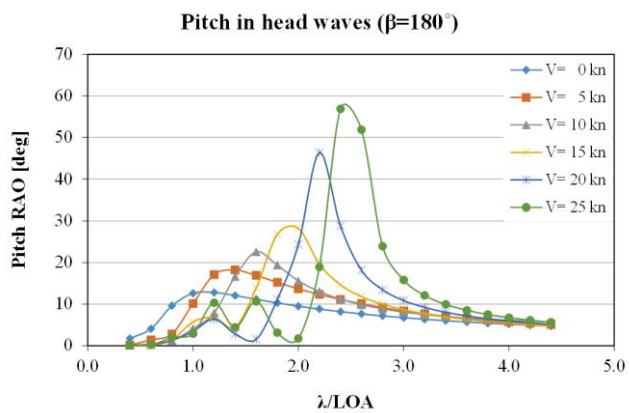


Figure 15. 3D panel method. Pitch RAOs in 1m amplitude head waves ($\beta=180^\circ$).

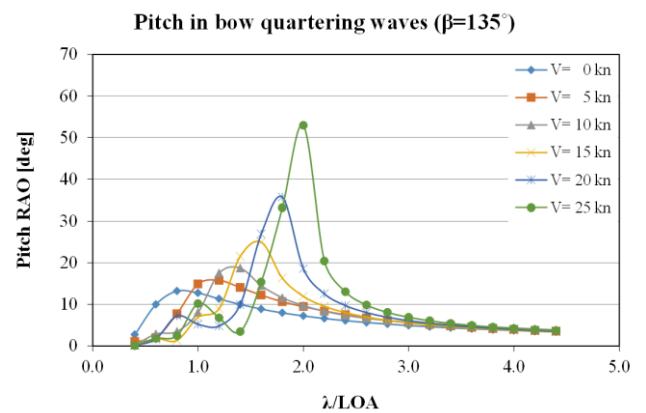


Figure 16. 3D panel method. Pitch RAOs in 1m amplitude bow quartering waves ($\beta=135^\circ$).

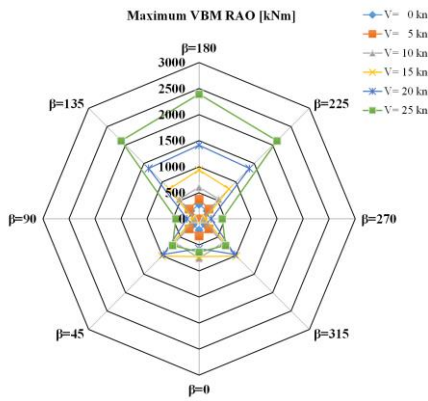


Figure 17. 2D strip theory.
Maximum VBM RAO.

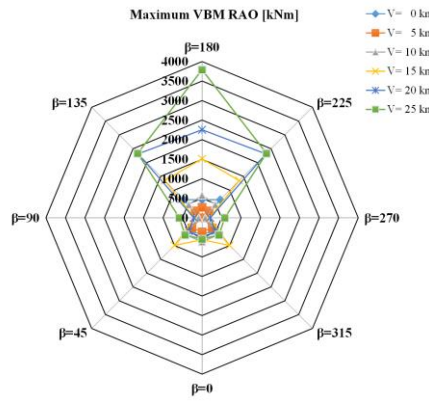


Figure 18. 2.5D strip theory.
Maximum VBM RAO.

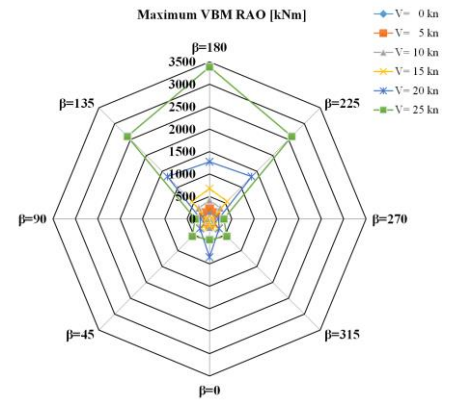


Figure 19. 3D panel method.
Maximum VBM RAO.

5. VALIDATION

The initial seakeeping predictions have generated some encouraging results. However, at this stage it is not possible to make any further judgement about their accuracy. Experimental tests are now necessary to validate and tune the numerical model.

Rigid body motions and hull girder loads will be measured in a variety of conditions through model tests carried out in a towing tank. Full-scale trials will also be performed to assess the motions of the craft and its structural response in real operational conditions. The results from these experimental tests will give insight on the accuracy of the predictions and on the presence of non-linear behaviour of the craft at speed. They will also make it possible to apply correction factors to enhance the predictive capability of the numerical model.

5. CONCLUSIONS

A numerical model of the Severn Class lifeboat that integrates hydrodynamic and structural analysis has been developed. A seakeeping analysis was performed to compute the pressure envelopes, rigid body motions and the global wave loads in regular waves. From an assessment of the motions and wave-induced load effects it will be possible to generate the load cases for a structural analysis. It can be concluded that:

- Linear potential theory is an effective tool for the prediction of the seakeeping motions and

loads in the various operating conditions. However, its limit lies in the ability to capture the hydrodynamics of a high-speed craft.

- Travelling in head and bow quartering seas subjects the craft to significant heave and pitch motions that increase to a great extent with speed. The maximum heave and pitch responses occur at wavelengths of 1.5 to 3 times the craft length. At shorter wavelengths, increasing the speed results in smaller motions. Heave and pitch responses in following and stern quartering seas are more challenging to analyse. For some combination of speed and wave frequency the vessel overtakes the waves and the motion responses may be considerably different.
- Despite the lower level of correlation amongst the codes used, the VBM in head and bow quartering seas shows a similar trend to that of heave and pitch motions. Peak values increase with speed as well as shifting to longer wavelengths. Maximum values are significantly lower in headings with wave direction abaft the beam. This suggests that the VBM in stern quartering and following seas does not represent an extreme response of the craft to be investigated through a structural analysis.

ACKNOWLEDGEMENTS

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REFERENCES

- [1] G. FRIDSMA, 1969 'A Systematic Study of the Rough-Water Performance of Planing Boats', Report 1275.
- [2] D. M. V. ROBERTON, 2015 'Residual Life Assessment of Composite Structures: With Application to All Weather Lifeboats', PhD Thesis, University of Southampton.
- [3] R. M. CRIPPS, C. CAIN, H. J. PHILLIPS, S. REES, AND D. RICHARDS, 2004 'Development of a New Crew Seat for All Weather Lifeboats', presented at the SURV 6: Surveillance, Pilot & Rescue Craft, London, UK, pp. 69–75.
- [4] H. J. PHILLIPS, P. J. SHEPPARD, G. VENNING, S. J. AUSTEN, AND S. HOUCHEN, 2009 'Theoretical and Practical Aspects of Conducting a Major Composite Repair', in *SURV7: Surveillance, Search and Rescue Craft*, Poole, UK, pp. 117–124.
- [5] M. R. RILEY AND J. MARSHALL, 2013 'Empirical Equations for Developing Ride Severity Envelopes for Planing Craft Less Than 55 Feet in Length', Combatant Craft Division, Code 83, NAVSEA, Report NSWCCD-83-TM-2013/36.
- [6] E. V. LEWIS, 1988, *Principles of Naval Architecture*, vol. 1 Stability and Strength. SNAME.
- [7] B. P. PHELPS, 1997 'Determination of wave loads for ship structural analysis', DTIC Document.
- [8] S. R. HELLER AND N. H. JASPER, 1960 'On The Structural Design of Planing Craft', *Quarterly Transactions, RINA*.
- [9] R. G. ALLEN AND R. R. JONES, 1972 'A Semiempirical Computerized Method for Predicting Three-Dimensional Hull-Water Impact Pressure Distributions and Forces on High-Performance Hulls', DTIC Document.
- [10] ABS, 2014 'Rules for Building and Classing High-Speed Craft.' American Bureau of Shipping.
- [11] DNV, 2012 'Rules for Classification of High Speed, Light Craft and Naval Surface Craft.' Det Norske Veritas.
- [12] LR, 2014 'Rules and Regulations for the Classification of Special Service Craft.' Lloyd's Register.
- [13] T. VON KÁRMÁN, 1929 'The impact on seaplane floats during landing', NACA.
- [14] H. WAGNER, 1932 'Loading of Seaplanes', NACA, Technical Memorandum No. 622.
- [15] A. B. STAVOVY AND S. L. CHUANG, 1976 'Analytical Determination of Slamming Pressures for High-Speed Vehicles in Waves', *Journal of Ship Research*, vol. 20, no. 4.
- [16] R. ZHAO AND O. FALTINSEN, 1993 'Water Entry of Two-Dimensional Bodies', *Journal of Fluid Mechanics*, vol. 246, p. 593.
- [17] R. ZHAO, O. FALTINSEN, AND J. AARSNES, 1996 'Water Entry of Arbitrary Two-Dimensional Sections with and without Flow Separation', in *Proceedings of the 21st Symposium on Naval Hydrodynamics*, pp. 408–423.
- [18] H. LE SOURNE, N. COUTY, F. BESNIER, C. KAMMERER, AND H. LEGAVRE, 2003 'LS-DYNA Applications in Shipbuilding', in *4th European LS-DYNA Users Conference*, Ulm, Germany, pp. 1–16.
- [19] V. BERTRAM, 2012, *Practical Ship Hydrodynamics*, Second Edition. Butterworth-Heinemann.
- [20] R. M. CRIPPS, H. J. PHILLIPS, AND C. F. CAIN, 2005 'Development of Integrated Design Procedures for Lifeboats', *International Journal of Small Craft Technology*.
- [21] ABS, 2011 'Guidance Notes on Structural Direct Analysis for High-Speed Craft.' American Bureau of Shipping.
- [22] C. ZHAO, M. MA, AND O. HUGHES, 2013 'Applying Strip Theory Based Linear Seakeeping Loads to 3D Full Ship Finite Element Models', in *Proceedings of the 32nd International Conference on Ocean, Offshore and Arctic Engineering*, Nantes, France.
- [23] M. MA, C. ZHAO, AND N. DANESE, 2012 'A Method of Applying Linear Seakeeping Panel Pressure to Full Ship Structural Models', in *COMPIT 2012 11th International Conference on Computer Applications and Information Technology in the Maritime Industries*, Liege, Belgium.